UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A DUAL FREQUENCY MICROWAVE MOISTURE SENSOR SYSTEM BASED CIRCULAR MICROSTRIP ANTENNA

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By

MOHAMED MUSTAFA GHRETLI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

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In
memory of my Mother,
the bright candle in my life.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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October 2005

Chairman: Professor Kaida Khalid, PhD

Faculty: Science

A dual frequency microwave moisture sensor based on far field reflection technique using two circular microstrip antenna pairs was developed and used to measure moisture content of various lossy liquid solutions. The sensor used two dielectric resonator oscillators as microwave sources in the X-band with oscillating frequencies of 8.48 and 10.69 GHz. Two wideband coaxial detectors were used to measure the amplitude of the reflected signals.

Theoretical calculation based on quasi-static cavity model with infinite ground plane approximation for circular microstrip antenna was carried out to evaluate design parameters such as antenna radius at resonance, efficiency, gain, bandwidth, feed point location ...etc. To this end a Visual Basic program was written and documented to evaluate all the design parameters needed

Antennas edge separation distances and E-plane configurations were considered carefully to reduce mutual coupling between elements. The final layout was printed on a single dielectric substrate. Radiation characteristics of the antennas, S-parameters and input impedances at resonance were measured using vector network analyzer and they compared satisfactory to theoretical simulations.

The optimum thickness of the sample holder and the air gap between the antennas and the sample holder were evaluated experimentally to ensure maximum signals at the detectors. Good agreements to theoretical expected values were found. The analysis of the complex electromagnetic waves in this reflected-type system is presented using signal flow graphs and solved by Mason's non-touching loops rules. The whole sensor system was interfaced to a personal computer through data acquisition card. This automated the calibration procedures and facilitated the switching time between the sources. Graphical user interface panel was written in LabView language to guide the user through calibration measurements and.

As an application example, the whole system was tested using diluted rubber latex with moisture content ranging from 39.8 to 95.2% wet basis. The sensor has predicted moisture contents with standard error of performance of ±0.49% moisture content using weighted average calibration method. Moisture contents of latex samples in temperature range of 25 to 63°C were measured successfully with an accuracy of ±1.3% MC wet basis compared to standard oven drying method.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBINAAN FREKUENSI DUAL PENDERIA MIKROGELOMBANG KELEGASAN BERGANTUNG KEPADA ANTENA BULAT MIKROJALUR

Oleh

MOHAMED MUSTAFA GHRETLI

Oktober 2005

Pengerusi: Profesor Kaida Khalid, PhD

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Penderia kelegasan frekuansi dual mikrogelombang dibina berasaskan teknik pantulan medan dekat dengan mengunakan dua pasang antena bulat mikrojalur dan digunakan untuk mengukur kandungan kelegasan pelbagai campuran cecair ketidakhilangan. Penderia itu mengunakan dua pengayun resonan dielektik, DROs sebagai punca pengayun gelombang pada frekuensi jalur-X dengan menjanakan frekuensi antara 8.48 dan 10.69 GHz. Dua jalur lebar pengesan sepaksi digunakan untuk mengukur ampitud isyarat pantulan.

Kiraan teori yang berasaskan model rongga kuasi-statik dengan satah substat tak terhingga penghampiran antena bulat mikrojalur telah digunakan untuk menilai parameter rekabentuk seperti jejari antena pada frekuensi resonan, kebekesanan

gandaan, lebar jalur, kedudukan titik sua dan lain-lain lagi. Dengan itu, satu program Visual Basic telah ditulis dan didokumenkan untuk mengira parameter rekabentuk yang diperlukan dan juga untuk menjangka keterusan antena dan E&H satah bentuk radiasi. Unsur impedan masukan radiasi telah dikira berasaskan pertegahan kedudukan titik suap dan juga paduan kepada komponen sistem yang lain untuk hataran kuasa maximum. Bentangan unsur berasakan sudut pamecahan dan satah E&H konfigurasi adalah ditimbang dengan teliti untuk pengurangkan saling ganbungan unsur antena itu. Bentangan terakhir yang dicetak pada substrat dielektik dan setiap unsure disambung kepada punca atau pengesan yang berkaitan melalui sambungan SMA sepaksi. Cirri-ciri radiasi unsur antena, parameter S dan impedan masukan pada resonan diukur mengunakan VNA sempurna dibanding dengan teori simulasi.

Pengoptimuman ketebalan pemegang sample dan pemisahan jarak antara antena dan pemegang sample tleah diadakan secara eksperimen untuk memastikan pengesan isyarat masimum pada pengesan bergantung kepada posisi masimum pertama dengan baik berbanding jangkaan teori. Analisa elektromagnatik gelembang kompleks pada sistem jenis pantulan adalah disembahkan dengan mengunakan graf gerakan isyarat. Nisbah gelombang kompleks pada titik mana-mana dalam sistem kepada isyarat masuk pada punca rujukan diperolehi dengan mengunakan peraturan Manson's perantaraan ulangan tak-sentuk untuk memudahkan analisis dan menghasilkan sistem pelbagai lapis, satu perisian, Tran&REF telah ditulis untuk mengira pantulan setiap lapisan perantaraan dalam sistem sehingga 6 lapisan. Perisian juga menyertakan telitian analisa setiap perantaraaan dan pantulan kiraaan dan juga kulit dalaman pada kedua-dua media pada pinggir antaraan.

Keseluruhan sistem penderia adalah diantaramukakan kepada satu komputer persendirian melalui kad pengantaraan muka National Instrument DAQ. Ia mempunyai kaedah automatik pententu-ukuran dan kedudukan pelaras masa antara punca. Akhir sekali, perisian ditulis dengan labView untuk sistem penderia dengan gambaran pengguna anntaraan-muka mudah . Ia mengarah penguna dalam beberapa langka bagaimana untuk jalankan pengukuran, simpan dan cetak file. Tanda amaran jelas ditayang jika tentu-ukur baru diperlukan. Dua papan elektronik berdedikasi telah dihasilkan dengan perisian Ultiboard. Tujuan pertama papan ialah untuk membekal voltan kepada pengayun dan lindungan daripada voltan berlebihan dan gandakan isyarat keluaran. Papan kedua menempatkan masukan analog dan sambungan pin antena digit kepada papan pengantaraan muka data dan kawal penentu punca melalui geganti keadaan pepejal.

Sebagai contoh aplikasi, keseluruhan sistem telah dicuba dengan menggunakan getah pada kandungan kelegasan daripada 39.8% sehingga 95.2% asas basah dan telah dijangkakan kandungan kelegasan dengan ketidakpastian piawai 0.49% kandungan kelegasan mengunakan kaedah penentuukuran timbang purata. Kandungan kelegasan sampel getah dalam julat suhu $25^{o}C$ hingga $63^{o}C$ telah berjaya diukur pada suhu berasingan. Kaedah penentu-ukur guna nisbah kuasa pantulan 2 jenis frekuensi dan teknik telah mengangkakan kandungan kelegasan asing pada suhu dengan ketidakpastian purata piawai 1.3% kandungan kelegasan asas basah.

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I certify that an Examination Committee has met on 19th October, 2005 to conduct the final examination of Mohamed Mustafa Ghretli on his Doctor of Philosophy thesis entitled "Development of a Dual Frequency Microwave Moisture Sensor System Based on Circular Microstrip Antenna" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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Date: 12 JAN 2006

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MOHAMED MUSTAFA GHRETLI

Date: 20 NOV 2005

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LIST OF ABBREVIATIONS

DRO	Dielectric Resonant Oscillator
VCO	Voltage Controlled Oscillator
VNA	Vector Network Analyzer
MMIC	Monolithic Microwave Integrated Circuit
DRC	Dry Rubber Content
MUT	Material Under Test
MC	Moisture Content
HPBW	Half-Power Beam Width
BW	Bandwidth
PLF	Polarization Loss Factor
SEC	Standard Error of Calibration
SEP	Standard Error of Performance
NDT	Non Destructive Testing
VSWR	Voltage Standing Wave Ratio
TEM	Transverse Electric Magnetic Fields
RF	Radio Frequency
HF	High Frequency
VHF	Very High Frequency
UHF	Ultra High Frequency
VB	Visual Basic
d.b.	Dry Basis Moisture Content Determination
w.b.	Wet Basis Moisture Content Determination

LIST OF SYMBOLS

E	Electric Field Intensity	(V/m)
H	Magnetic Field Intensity	(A/m)
S	Poynting Vector	(W/m^2)
ε_0	Permittivity of Vacuum	(F/m)
μ_0	Permeability of Vacuum	(H/m)
ε^*_r	Relative Permittivity (Complex)	(dimensionless)
μ^*_r	Relative Permeability (Complex)	(dimensionless)
η^*	Medium Impedance (Complex)	(Ω)
L	Inductance	(H)
C	Capacitance	(F)
R	Resistance	(Ω)
G	Conductance	(S)
X	Reactance	(Ω)
B	Susceptance	(S)
Z	Impedance	(Ω)
Y	Admittance	(S)
γ^*	Propagation Constant (complex)	(1/m)
α	Attenuation constant	(1/m)
β	Phase Constant	(rad/m)
δ	Skin Depth	(m)
σ	Conductivity	(S/m)
ω	Angular Frequency	(rad.Hz)

ε'	Dielectric Constant	(F/m)
ε''	Loss Factor	(F/m)
$\tan\delta$	Loss Tangent	(dimensionless)
Γ^*	Reflection Coefficient (complex)	(dimensionless)
τ^*	Transmission Coefficient (Complex)	(dimensionless)
D	Directivity	(dimensionless)
G	Gain	(dimensionless)
e	Efficiency	(dimensionless)
Q_T	Quality factor	(dimensionless)
RL	Return Loss	(dB)
M	Mutual Coupling	(dB)
a	Radius of the Disk	(cm)
ρ_0	Feed Radius	(cm)